2 CONCEPTS IN ENGINEERING DESIGN – AN INTRODUCTORY COURSE IN DESIGN OFFERED IN UNDERGRADUATE ENGINEERING CURRICULUM

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"Concepts in Engineering Design" is a core course offered to all the first year undergraduate students in engineering at the Indian Institute of Technology, Madras. The primary objective of the course is to introduce concepts in engineering design to students from all the engineering disciplines through a 2-credit programme. The course is conducted in conceptually different manner with inputs from faculty volunteers from different engineering disciplines. Over the last 10 years of the programme, a significant number of students have been found to appreciate engineering design and the inter-disciplinary roles of engineering and science in designing and delivering products or processes. This paper will discuss the origin and motivation of the course, its evolution, the methodology and approach followed in teaching the course and evaluating the students.

Some of the lectures in this course cover theoretical and conceptual aspects associated with the design process. However, since the students attending this course are novice to engineering terms, we find that emphasising on the conceptual aspects of design including associated terminology, is not very effective. Therefore, emphasis is given to case studies, hands-on model making and assignments. In particular, we use examples of common products/structures and explain how the design of the product/structure has evolved with time. Examples like the evolution of the design of aeroplane, ships, portable energy devices, CD disc drive, fountain pen; climate conscious design of buildings; green design concepts etc. are used for case studies.

Innovative approaches are adopted to teach the course to large classes of 500-600 students in each batch using audio-visual facilities. Examinations and design evaluations are also innovated to account for the large number of students in the course. Assignments, examinations and design contests with more open-ended approach are used for evaluating the students. These are aimed at testing the concepts learned in the class as well as the general observation skills. Design contests are meant for small teams of students to build something from the given topics. They are evaluated for accuracy with respect to task, use of innovation, aesthetics, performance, approach, team work etc. Examples of model making assignments could be to build a chair to seat a regular adult, using newspaper and sticking tape; build a bridge using broom sticks etc. We discuss the many novel aspects of this course in terms of its concept, content, evolution, delivery and evaluation.

Keywords: Introductory Course, Innovation in Teaching, Design Concepts

1. INTRODUCTION

For the past ten years, the Indian Institute of Technology, Madras, has been pioneering an introductory engineering design programme for the first semester undergraduate students in Engineering titled

"Concepts in Engineering Design" (ID110). The course is a unique experiment in the Indian context, since no other IITs or other prominent Engineering/Technology institutes in India offer such a course. However, there are many such courses offered by various Institutes around the world.[1–6] The lack of such a course in India at the introductory level, invites special attention to the need for such courses in engineering curricula and the success of this course can build confidence in conducting such courses. IIT Kanpur experimented with a similar course in the 70's and discontinued it.

At the US Air Force Academy (USAFA)[3] Engineering 100 is a required course for all students. Engineering 100 takes an innovative approach to first-year engineering education by introducing engineering in the context of the design process. Students are organized into teams and are given assignments geared towards hands-on exposure to five engineering disciplines: astronautical, aeronautical, mechanical, electrical, and civil. Faculty from each of the five engineering departments at the Academy, teach the course, reinforcing the multidisciplinary nature of engineering projects.

A similar course conducted at the Colorado State University, in a lecture-laboratory mode, offers a variety of "hard" (technical) and "soft" engineering subjects put into practice. The course offers a group design project, with the overall goal of providing students with a sense of the engineering discipline while being both challenging and fun.[4] The Introduction to Engineering Design course (ENGR 100) at the University of Washington has proven to be a successful vehicle for connecting the fields of engineering and education.[5] ENGR 100 is a project-based design course in which both faculty and students work in teams. Each section is taught by an engineering Professor, a graduate teaching assistant and an undergraduate senior peer. The students work in teams to complete a number of design research assignments as also reverse engineering. The Introduction to Engineering Course at the University of Southern Maine[6] is a creative introductory design and construction experience that provides students opportunities to acquire knowledge and practice needed skills. The design project includes sufficient science, mathematics and design principles so that it is not simply a build-and-try effort.

At IIT Madras ID110 has been using many innovative approaches in teaching the course which have not been experimented in the country much less been offered to a large number of students. In this paper, we detail the philosophy behind this course, how it has evolved, the logistics, and the methodology followed to sustain successfully the "spirit of open approach" in delivering the course.

The course number, ID 110 uses the prefix 'ID' to indicate that the course is 'Inter-Disciplinary' in nature. This aspect of the course is emphasized by offering the course to all the engineering disciplines in the Institute as well as by having teachers from different disciplines. It is a two credit course, with two hours of lectures each week. Currently about 580 students are enrolled in the course (2008). There are no laboratory classes associated with this course, however, students are required to carry out hands-on design projects and assignments as part of the course.

ID110 traces its origins to the time when the five-year undergraduate programme was changed to four years in 1982. At that time, it was felt that engineering students of all disciplines must be exposed to practical aspects associated with Engineering so that they appreciate the philosophy behind engineering and the design of products/structures/processes. Therefore, a course on Engineering Design was proposed to be included in the curriculum. However, it was several years before this was actually effected. In 1997, a curriculum revision committee formally recommended starting a course of this nature. The resulting course, ID110, has been taught since 1998, and has now completed a decade.

2. PHILOSOPHY

Undergraduate students entering the engineering programmes at IIT typically undergo evaluation of their skills in Physics, Chemistry, and Mathematics through an All India entrance examination. Conventionally, students learn more Physics, Chemistry, and Mathematics during their first few semesters and then get exposed to the technical details relevant to their specific disciplines in the higher semesters. However, for a student of Engineering, it is necessary to also understand the aspects associated with developing successful products/processes/structures in addition to knowledge of the technical details associated with the discipline. Teaching fundamentals of design to incoming undergraduate

students can prepare them for exposure to actual design in courses offered subsequently. It is important for students to appreciate design even if they are not able to actually do the design. The ID110 course at IIT Madras aims to expose the student to all concepts and issues which go into design.

For a course to be effective, its curriculum has to be designed with emphasis on requirements, specifications, design and testing, with examples of items from different disciplines. It is therefore important to expose the student to practical design through examples. It is a challenge to structure the course to meet these requirements. The course content should not overly emphasize technical details but expose the student to the requirements of design.

2.1. Preferred Approach to Teaching

Though there is an outline and a few textbooks suggested for the course, ID110 has been delivered without strict adherence to a specific curriculum. This is based on the spirit of approaching design problems with an open mind and encouraging students to ask the right questions to arrive at a preliminary design whether it is a product or structure or a process that they are looking at. Design competitions showed different models developed by students who have had no prior exposure to design methodologies. In this approach teachers from different disciplines who offer lectures choose the topics themselves and there is no pre-assigned examples taught by anybody. The lectures, case studies and assignments offered by each teacher generally centre around the concepts introduced in the beginning of the course but bring in variety, originality, innovativeness and effectiveness. In this course we emphasize the importance of human interface, documentation and the need to understand standards. It will be necessary to relate design issues to mathematics and basic sciences so that the student gets an integrated view of science and technology. Above all, design is an art- the personal touch of the designer or a novel approach to a problem always matter.

3. LOGISTICS

One of the major challenges in offering ID110 has been the need to handle very large classes. It has been an interesting exercise to design the course such that the intent of conveying aspects of design to each student is accomplished, while at the same time, it is possible to administer the course to a large class. Innovative approaches to seating of students, recording attendance, sharing study material, and evaluation schemes have been adopted to deliver the course. These approaches have themselves evolved over the past ten years.

3.1. Delivery of Lectures

The schematic shown in Figure 1 explains how the teaching methodology and logistics have evolved over the last ten years, accommodating the requirements explained earlier.

During the initial years, students were split into two batches. Each lecture was repeated in a week for approximately 200 students in the class where the total enrolment was typically 400. Problems associated with this mode of teaching were the uneven distribution of classes between the batches if there were unanticipated holidays. For the evaluation of students, assignments, quizzes, and hands-on model making design contests were used. To handle the evaluation of assignments, the innovative approach of using sixth semester students who were already exposed to the course, as Teaching Assistants (TAs), was adopted. Non-uniformity in grading among the various TAs was taken care of by normalizing the marks. This system of evaluating the assignments worked quite well for about 6 years until it became difficult to get student TAs. About eight assignments (one per each faculty/topic) were given during this period engaging the students in a multitude of design related problems/issues.

3.2. Student Evaluation

Student evaluation consisted of a quiz, a final exam, assignments and a design competition. The exams were aimed at testing the student's grasp of the subject as taught in the class as well as acquired through

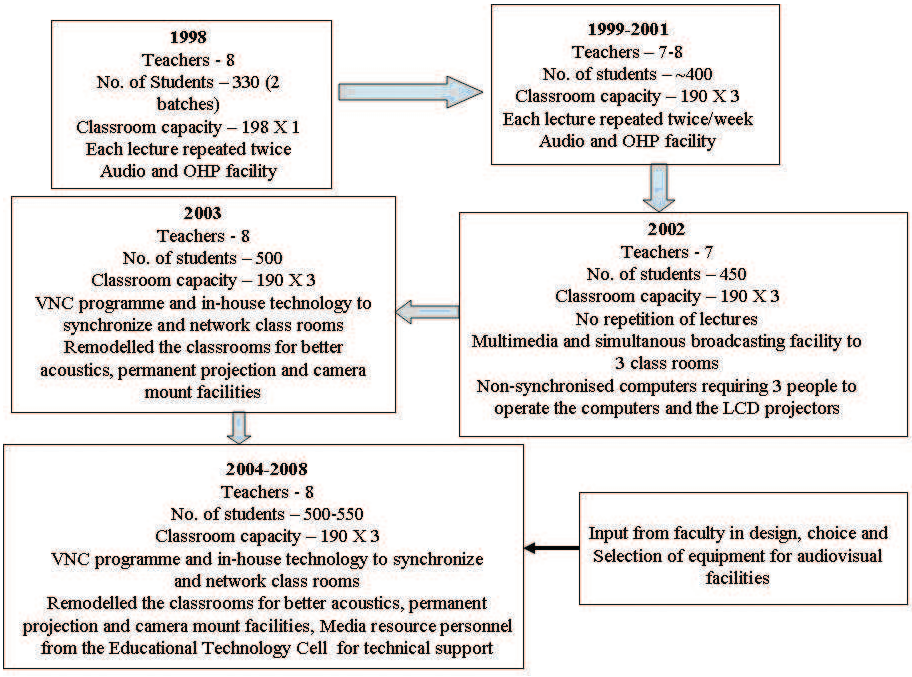

Figure 1. Schematic showing the evolution of the teaching methodology of ID110.

observations, experience etc. These exams had a significant element of "open-ended approach" to solve the given problems. The evolution of the various methods used in evaluating the students over the years is summarized in Figure 2.

The quizzes looked for details of existing designs like functional requirements (e.g. type of load acting on cycle spokes), their advantages and drawbacks (e.g. compare a spiral staircase design with a straight one), or to look at designs in nature and learn from (e. g. spiders web, bird flight etc.). Assignments had questions such as "measure the height of a water storage tank at a specific location" — a distance of approximately two kilometers. Students had to think about techniques to measure distances of that order, complete the measurement, and indicate their estimate of sources of error and extent of error. These experiences are meant to bring out the importance of accuracy in engineering designs and the need to include error estimation. Clear instructions were given for solving the assignment and writing the reports. The ethics to be followed in the course was also explained to the students in advance. Design contests required students to build models and included topics such as "build a bridge or cantilever beam made of broomsticks and other cheap and eco-friendly materials". The bridge /cantilever designs were evaluated based on the ratio of the maximum weight it could carry, to its self weight.

3.3. Course Administration

Administering this course demanded a lot of time and effort and dedication from the faculty members. In subsequent years modifications were made to various aspects of the course so as to ensure that the rigor of the course was maintained, while the effort required was relatively reduced. This included changes like utilizing multiple classrooms where simultaneous, synchronized teaching could be done using audio-visual facilities.

The teacher taught in one of the rooms and the video of the lecture was telecast to the adjacent two rooms. Faculty volunteers in each of the rooms independently operated computers to ensure that appropriate slides were projected on the screens and shown to the students at the correct time. In due course, with establishment of LAN connections between the rooms and the use of appropriate

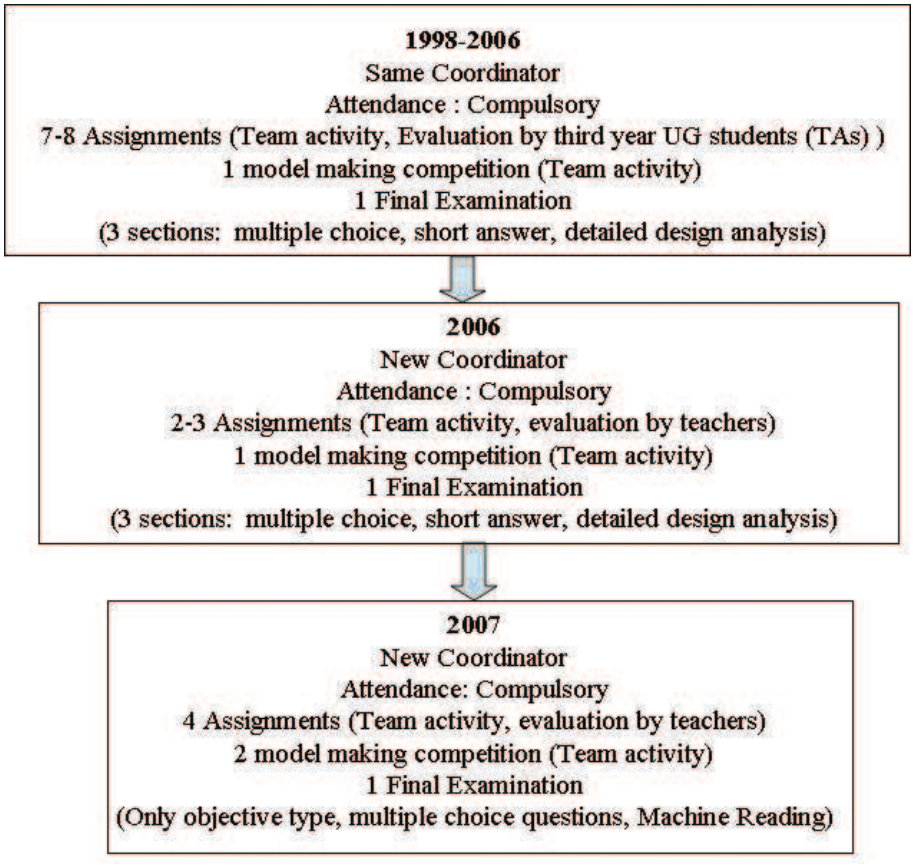

Figure 2. Evolution of the evaluation methodology followed from 1998- 2007 in ID110.

software (VNC), simultaneous telecasting of the lecture and the slides to all the three rooms became possible (Figure 1). However, the electronic mode of teaching has its disadvantages such as reduced student-teacher interaction during the class and low span of attention.

Students were assigned specific seats and the rooms where they would sit were sequenced to ensure every one had a direct contact with the teacher for a specified period (typically a month). This also helped in recording the attendance in an effective manner. Attendance sheets were circulated in a specific order which matched the seating arrangement. TAs and faculty ensured that attendance was signed and collected while the class was being conducted in five minutes or less.

Faculty members with interest in design were drawn in from various departments to run the course. This is a very important aspect since the long-term sustainability of such interdisciplinary course depends a lot on the interest and commitment of the faculty. After a few introductory classes on general aspects of the design process, each faculty taught two to three classes in which she/he discussed a design process relevant to an area (e.g. material selection in engineering design, what is meant by a bad design, design of an aircraft etc.) with the help of appropriate case studies.

After the first year of this course, it was felt that the use of text books to teach the course was not very effective. With multiple faculty, from different departments and research background, exposing students to various aspects of design using case studies, became easy. Taking advantage of resources such as the internet, study material in the form of limited class notes and links to related sites were made available on the internet/intranet for the benefit of students. The course website is useful for both administering the course and reaching out to the students. Evaluation results, important announcements

related to the course, assignments and design contest, model making guidelines, photographs of best designs and best assignments etc. are made online.

4. EXPERIENCES AND OBSERVATIONS

Students in the first semester, have little background in engineering/advanced science required to understand detailed design concepts. Therefore, it is expected that students will not be able to relate to the formal aspects of the course if taught using the conventional and more formal terminologies used in design. Therefore, a larger fraction of the lectures are devoted to case studies. In particular, the students get to look at commonplace products and understand how the design of the product has evolved with time. Students learn how the original product looked like and how its design evolved in response to user demands placed on the product, and examine the processes and other considerations taken into account as the design evolved.

For example, in one case study, students were shown how the design of a fountain pen has evolved from the time a quill was used for writing. The faculty asks questions such as "how can the ink be stored conveniently and released in a controlled manner to the paper?", "what is the need for the hole in the nib?", "what are the materials suitable for each component in the pen?" etc. and ends the case study by discussing each component and its function and how each material/process is chosen to suit the product. Topics covered include climate conscious design of buildings; green design of products/buildings; TRIZ (the Russian concept of learning from solutions to technical problems in other fields and applying it to one's own field); fuel cells — the journey from concept to product; design of portable energy devices to suit specific applications, the design of an aero plane – in particular how the design would be odd and unpractical if any one team of engineers were allowed to dominate the design process; learning from nature about design — how the design of ship is similar/different from that of a fish etc.

Assignments, quizzes (examinations) and design contests with an open-ended approach were used for evaluating the students. Examples of assignments/topics for model making given in the past show the innovative, exploratory, open-ended and contextual nature of them. Some examples are given below:

- "Imagine and describe how the design of a bicycle will evolve over the next ten years"; design, and show using a diagram
- Measure the distance between the IN gate of IIT and Gajendra circle along Delhi Avenue. Your measurement should be correct to about five to ten Meters. (The distance is greater than 2 Kilometers) etc.

The assignments are submitted by a team of three students and are expected to include: (1) statement of the design problem, (2) Need Analysis (3) Specifications (4) Design details (4) Limitations and (5) General observations about the design.

Examinations tested the students in concepts they learnt in the classes as well as their general observation skills. For example they were asked to estimate the volume of the room they were seated in, the frequency of the a.c supply they received at home etc. They were also asked to suggest designs to address specific needs — such as the design of a hat that can with minor modifications, be appropriate for all of the weather conditions one may experience in Chennai.

The design contests involve hands-on experience in making models in teams of three students. The items to be designed have been chosen specifically to enable the students build them using components they have access to. Designs involving Electronic components or mechanical parts can certainly make the exercise more interesting but we have no resources to provide the hundred and twenty groups with the items they would require. For this reason, the design competitions have centered around items where the students gain experience in building something but not necessarily make it into a usable product. Students are given three to four weeks' time to build, test and iterate their designs. The students are also expected to submit a design report. Example of a problem given in the past is given below:

Design a cantilever truss as per specifications shown in Figure 3. The truss must be built only from the bristles in the broom made of coconut leaf backing. You will be given a plywood plate with holes drilled as shown and the truss should be anchored at these four holes with glue. The design will be tested by loading the cantilever and the winning design will be the one which takes maximum load per unit weight of the truss. The weight of the plate will not be included in the weight of the truss. One of the models on the testing rig is shown in Figure 4.

5. WHAT HAVE WE LEARNT BY OFFERING THE COURSE?

The past decade (1998-2007) during which this course has been offered has been an interesting learning experience in terms of how to conduct a course of this nature. Some of the important observations are summarized here. Interested and committed faculty from various departments, are a vital aspect for the successful delivery of such a course. The course material must take into account the educational level of the student audience — too much of technical jargon is not very helpful for students to appreciate the course. The challenges of handling large classes may be handled with innovative approaches using Multimedia devices.

Evaluation of students should include a variety of examinations — descriptive and analytical examinations and assignments, hands-on model making assignments and design contests, multiple choice examinations, individual and team skills etc., to capture the diversity of the learning experience this course offers.

Despite the large number of students in the class, failure rate is almost insignificant and there are no serious or major complaints from students regarding the evaluation methods followed. A unique course of this nature is a very satisfactory experience for the faculty as well as the students involved. Feedback was collected using a questionnaire prepared for the course and analyzed every year. Sample data analysis done in 2007 is given in Table 1.The data show that the course has received good feedback and this was reflected in the earlier feedbacks too. To quote a former student, "*ID110, The introduction to engineering design is a course that tops the list of unforgettable courses, for many people. It is very*

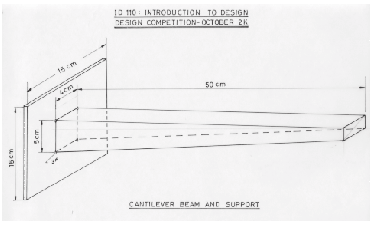

Figure 3. Specifications for the Design.

Figure 4. Testing Rig and a unit under test Competition.

Table 1. Student feedback in 2007 (Number of students participated in the survey – 484).

Question	Answer
Was the course meaningful at all?	Yes -88% No – 5%
Did the course motivate you to think and solve problems as opposed to a standard solution?	Yes – 80 % No – 8 % Can't say – 12%
In a broad sense, did the classes coherently add to each other?	Yes - 68% No – 32%
The contents of the course were easy to understand	Definitely yes – 20 % Mostly yes – 72% Mostly no – 7% Definitely no – 3%
Do you think this course should be retained in the curriculum? And offered in the same fashion (i.e case studies, design contests, assignments and exams)	Yes -73% No – 4% Change the pattern – 19% Move to another semester – 4%
Give your overall rating for the course	Very Good – 28%, Good – 55% Satisfactory - 15 %, Poor – 2%

different from all the courses that you will do, and is unique because it evokes almost all the varied responses from everyone. A very satisfying course though it can be frustrating, it is one that has a practical tinge and is very often the hallmark course of the first semester". [7]

6. SUMMARY

ID 110, Concepts in Engineering Design, an introductory course in Engineering Design, has been successfully offered for the past 10 years at the Indian Institute of Technology, Madras. The course is offered simultaneously, to about 500-600 students from various engineering disciplines. The teaching and evaluation methodologies have evolved over the last ten years to handle the unique challenges posed by this course. Innovative approaches based on multimedia assisted teaching methodologies and a variety of evaluation techniques which provide hands-on experience, have been implemented in this course. Feedback from the students indicates that ID110 provides the students with a fresh and interesting learning experience in appreciating engineering design.

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